U.S. DEPARTMENT OF ENERGY
Office of Electricity

Integrated Distribution System Planning

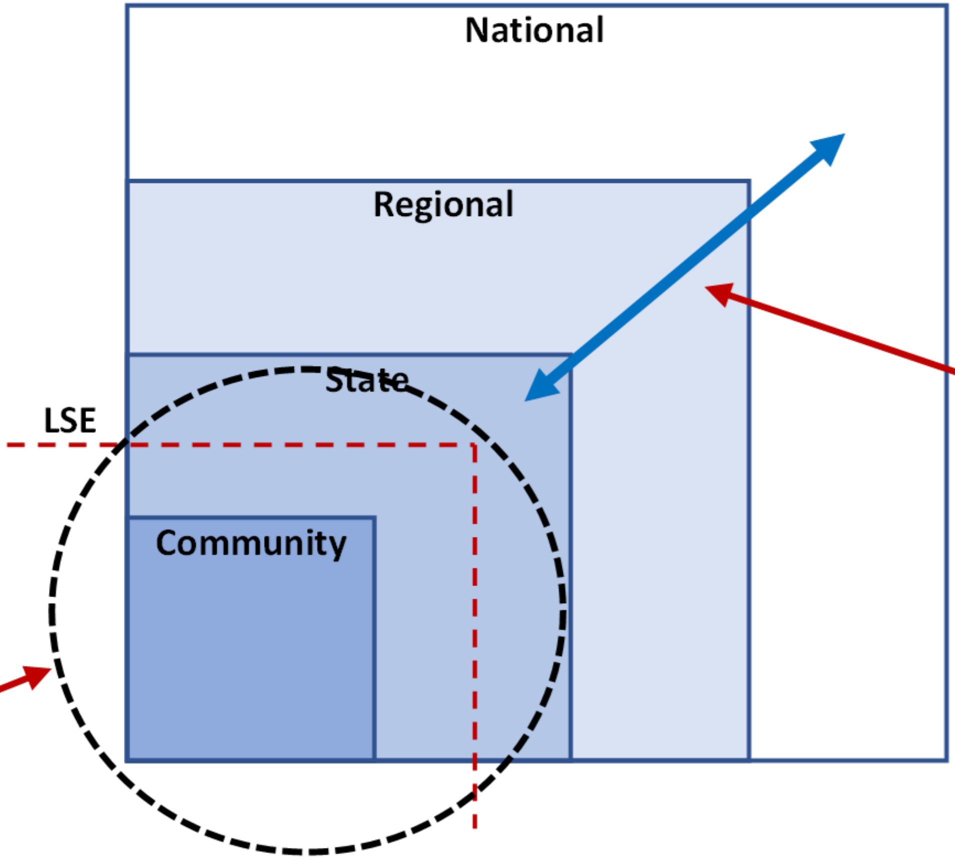
Principles and Approaches

Integrated Planning Team
Office of Electricity
US Department of Energy

November 4, 2023

Scale of Integrated Planning

Address state/community objectives through an IDSP process and align with regional planning efforts



Alignment of community and state strategies with regional, multi-state strategies

IDPs align community and state policy goals into multi-year investment strategies

Integrated Distribution System Planning (IDSP)

Distribution planning across the U.S. addresses 3 key overlapping areas of focus to meet customer needs

Key considerations:

- Convergence of state energy policy objectives and priorities with utility/3rd-party planning processes
- Integration of customer and 3rd-party systems with utility systems
- Coordination, utilization, and orchestration of distributed energy resources (DERs)
- Improvements in reliability, resilience and operational efficiency
- The application of advanced sensing, communications, control, information management, and computing technologies to enable the above
- The application of grid architecture and a focus on structure to ensure the building of a coherent system that is scalable
- Business process redesign and multi-jurisdictional coordination to effectively integrate planning, grid operations, and market design/operations

IDSP Maturity

Twenty-two States have IDSP processes underway at various levels of maturity and complexity

California AB327 (2013)
Hawaii Docket 2014-0192 (2014)
Minnesota Docket CI-15-556 (2015)
New York REV Proceeding 14-M-0101 (2015)

- Effective integration/utilization of DERs
  - Reduce interconnection queues/costs
  - Interconnection standards (inverter functions)
  - Hosting capacity analysis
  - Locational benefits assessment
  - NWAs
- Load and DER forecasting
- Customer empowerment (AMI focus)
- Grid reliability, resilience, & flexibility
- Grid modernization strategy (pace & valuation)
- Strategy for capital investments (5-10 yr horizon)

Increased level of complexity →

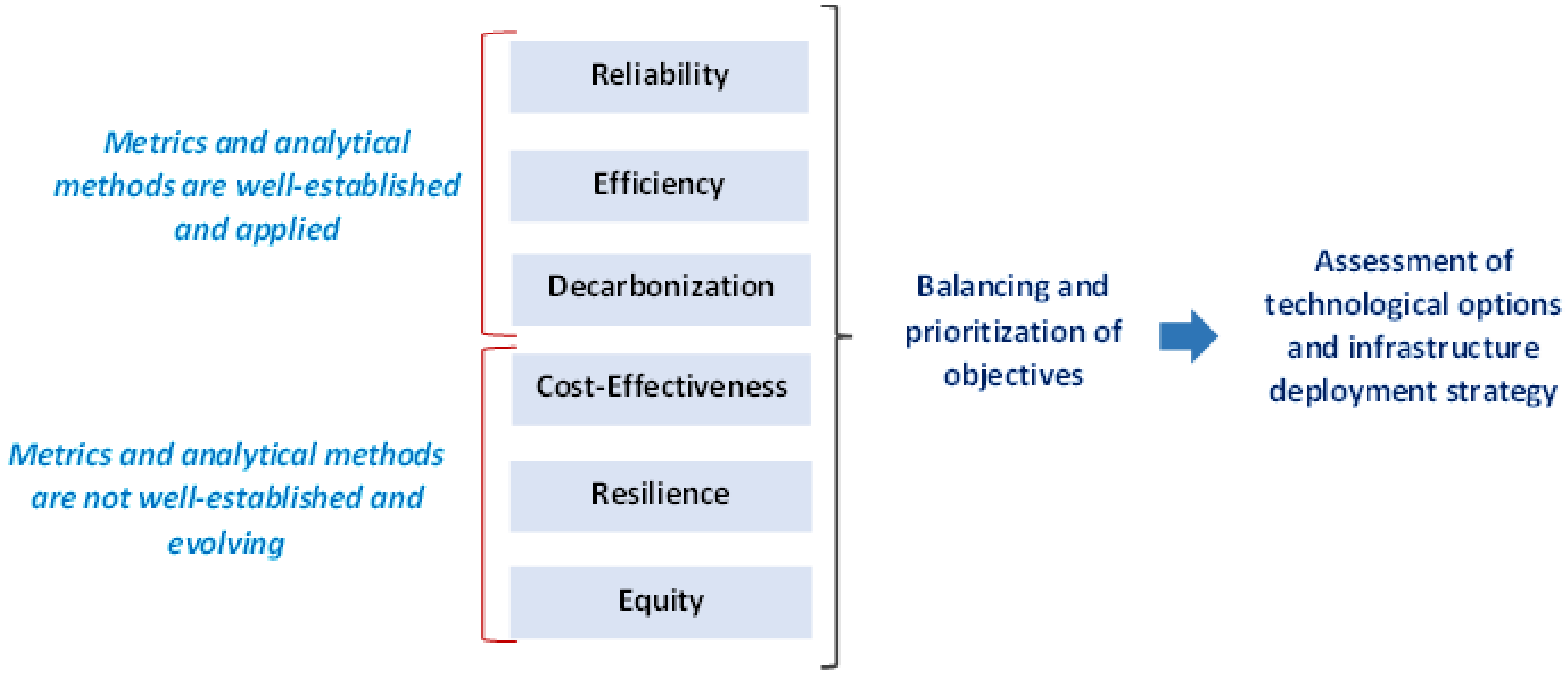
Today (2023)

- Effective use of DERs in T&D markets (FERC 2222)
- DERs to enable load flexibility & resilience
- Forecasting load, DER adoption, & climate parameters
  - Electrification
  - Impact of climate on assets
- Community engagement
- Benefits to vulnerable/disadvantaged populations
- Prioritization of investments across multiple objectives
- Cost-effectiveness of proposed investments
- IDP/IRP synchronization

References:
- State Engagement in Electric Distribution System Planning, December 2017, PNNL-27066, State_Engagement_in_Electric_Distribution_System_Planning_PNNL_27066.pdf
- Distribution System Planning – State Examples by Topic, May 2018, PNNL- 27366, DSP_State_Examples-PNNL-27366.pdf

Objectives-Based Planning

A well-designed integrated distribution system planning process provides a framework for translating policy objectives, metrics, and priorities into holistic infrastructure investment strategies



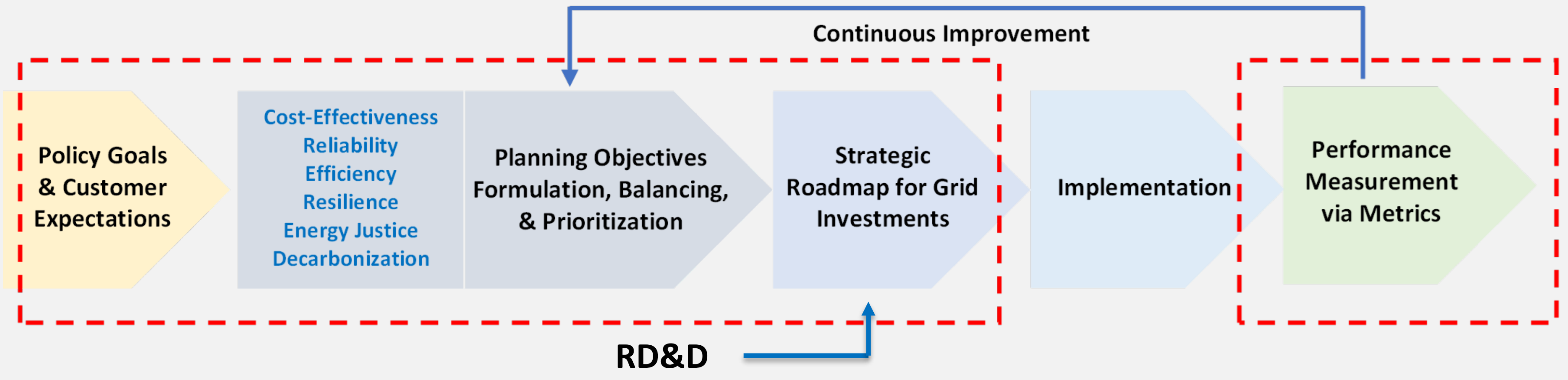
Decision Process Framework

Three interrelated components that form a framework to organize and inform decision-making

Roles and Responsibilities of Participants

Roles and responsibilities of decisionmakers and stakeholders within the decision process

Decision Process



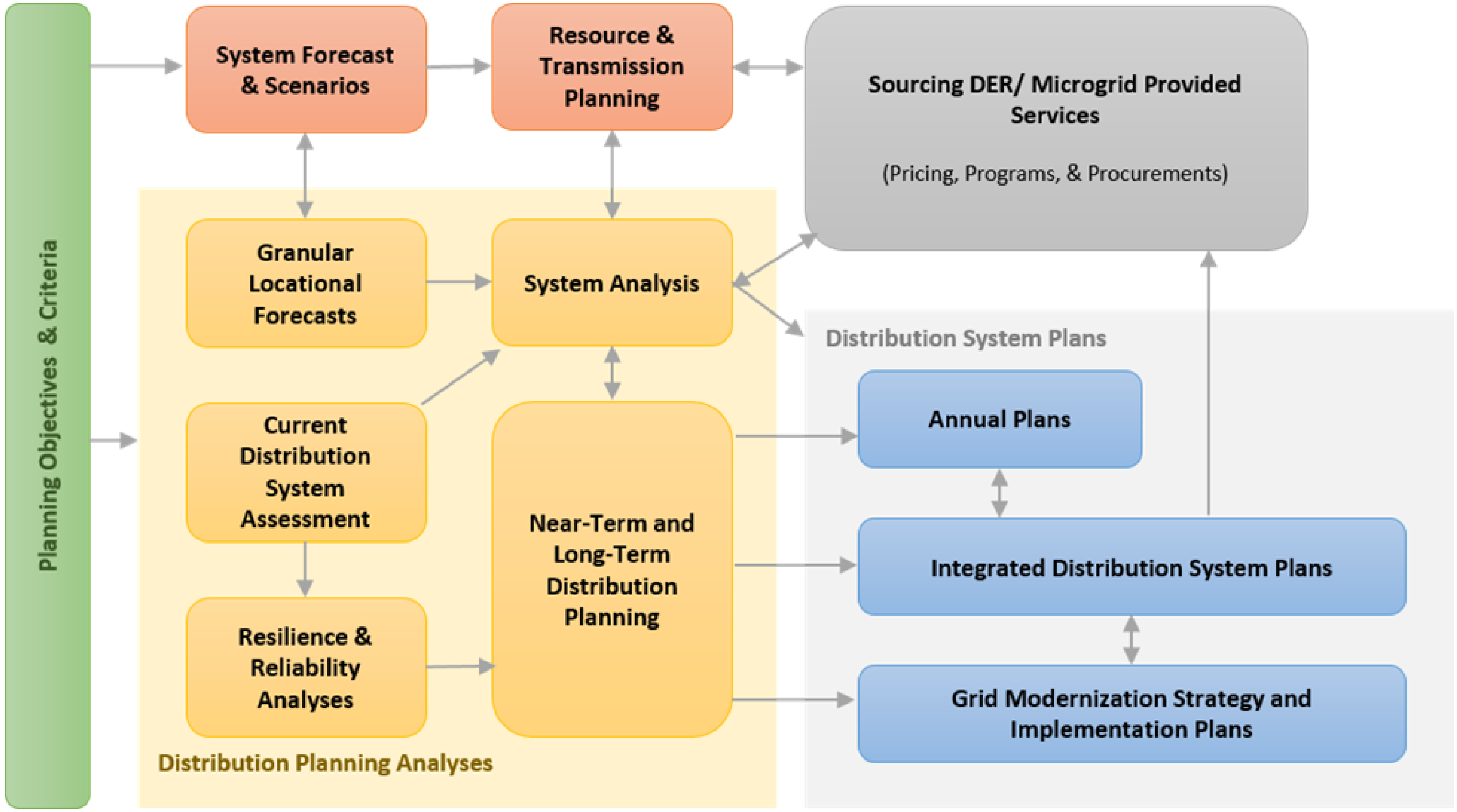
Supporting Analytical Methods and Tools

To inform decision-making within the decision process

IDSP Components

IDSP provides a decision framework for integrating a variety of processes beginning with the setting of planning objectives/criteria and assessing scenarios (including forecasts of customer demand and DER/EV adoption) and resulting in long-term grid investment and modernization strategies

Planning objectives, metrics, and priorities are derived from state & community policies and customer needs



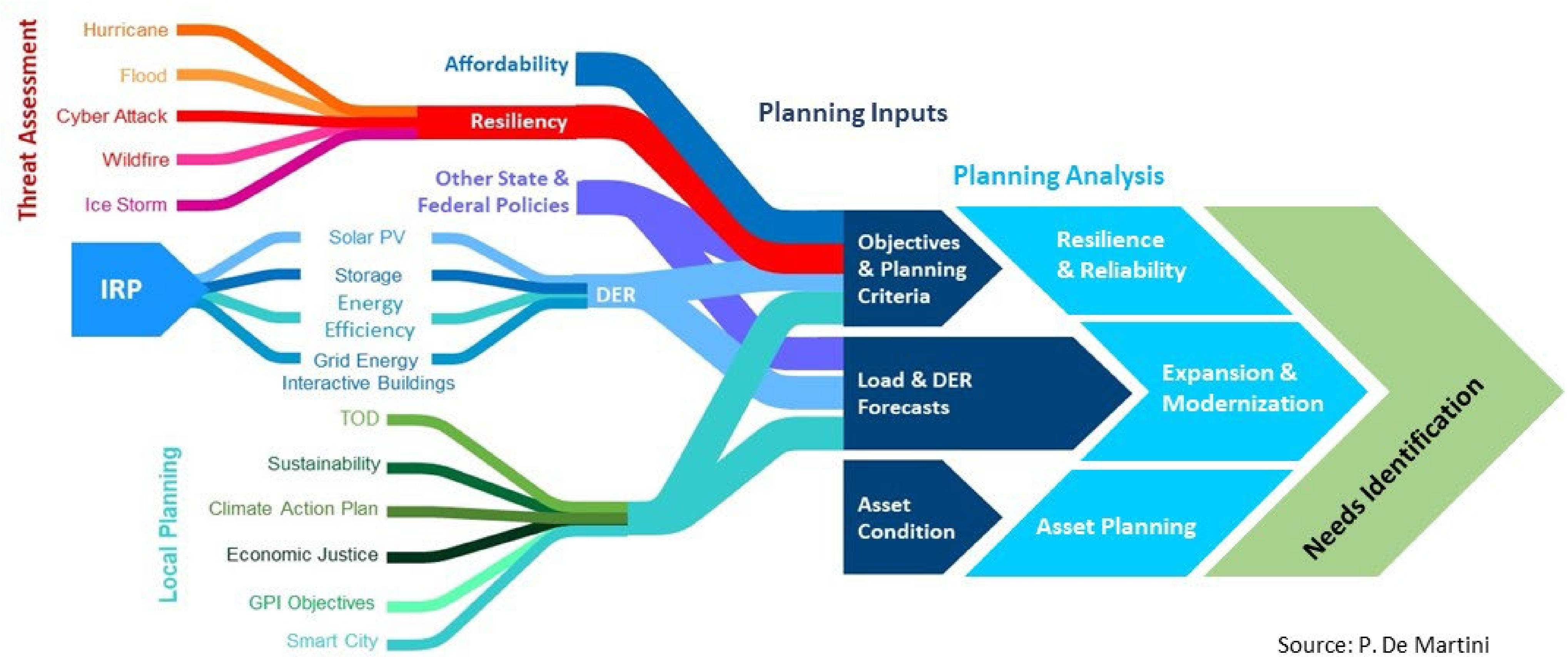
Regulators* review and approve plan with input from stakeholders

*The term "regulators" includes the approving boards of cooperative and municipal utilities

From Modern Distribution Grid Guidebook, DSPx Volume 4, June 2020, [PNNL: Grid Architecture - Modern Distribution Grid Project]

Emerging Distribution System Planning Inputs

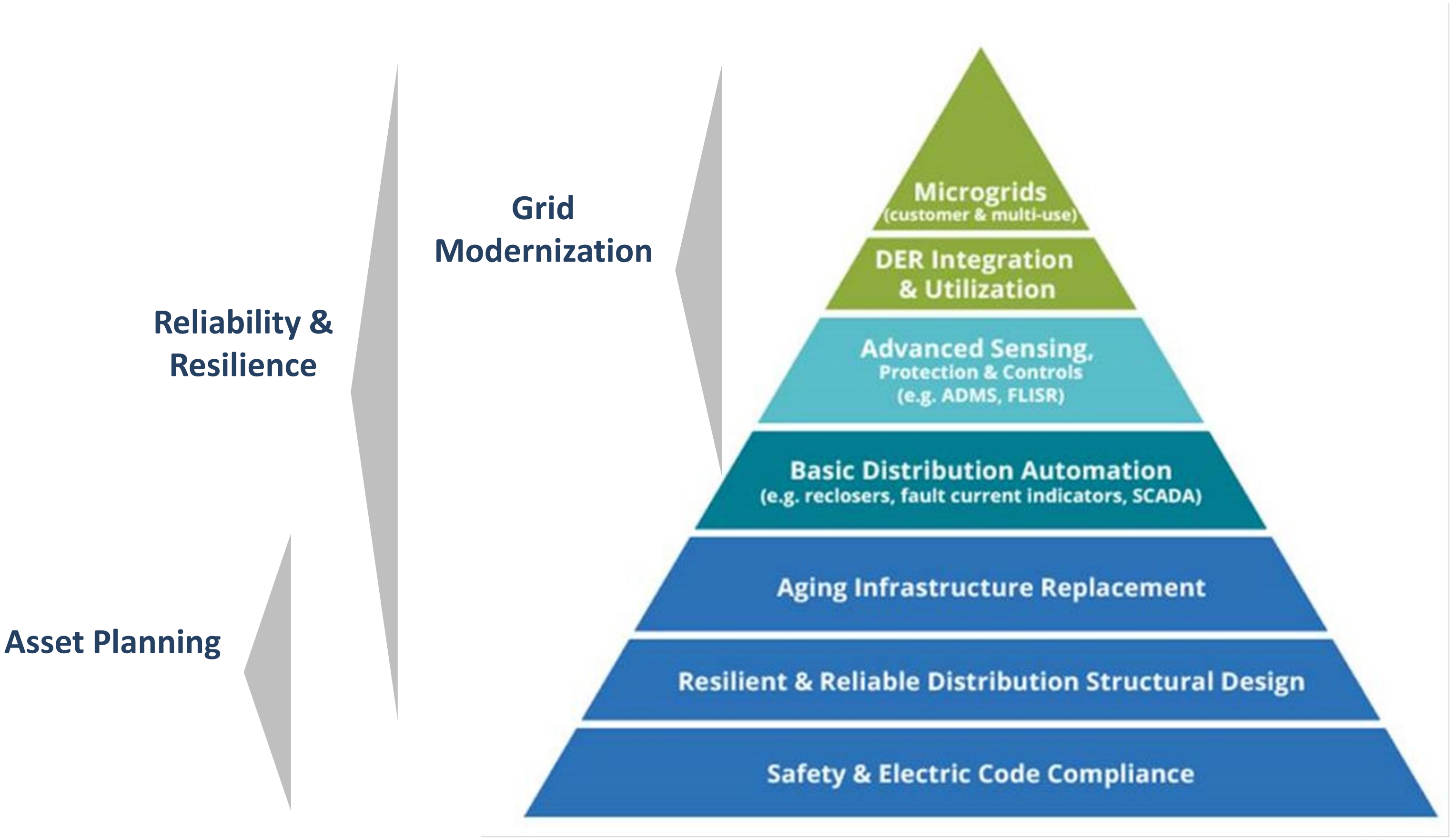
Distribution planning increasingly dependent upon IRP/bulk power planning, local sustainability & resilience plans, and use of DER



Source: P. De Martini

Distribution & Modernization Investment Categories

Grid modernization technologies layer on top of & integrate with foundational physical grid infrastructure. Foundational investments are required to ensure reliability and resilience while enabling more advanced grid operations.



Source: De Martini

Spectrum of Resilience Measures

Less sophisticated, yet foundational

More sophisticated, requires advanced grid capabilities

- Hardening infrastructure
- Ensuring adequate emergency management capabilities
- Back-Up provisions (e.g., fuel)

Robust Asset Management:
- Asset monitoring
- Failure prediction
- Data analysis (GIS)

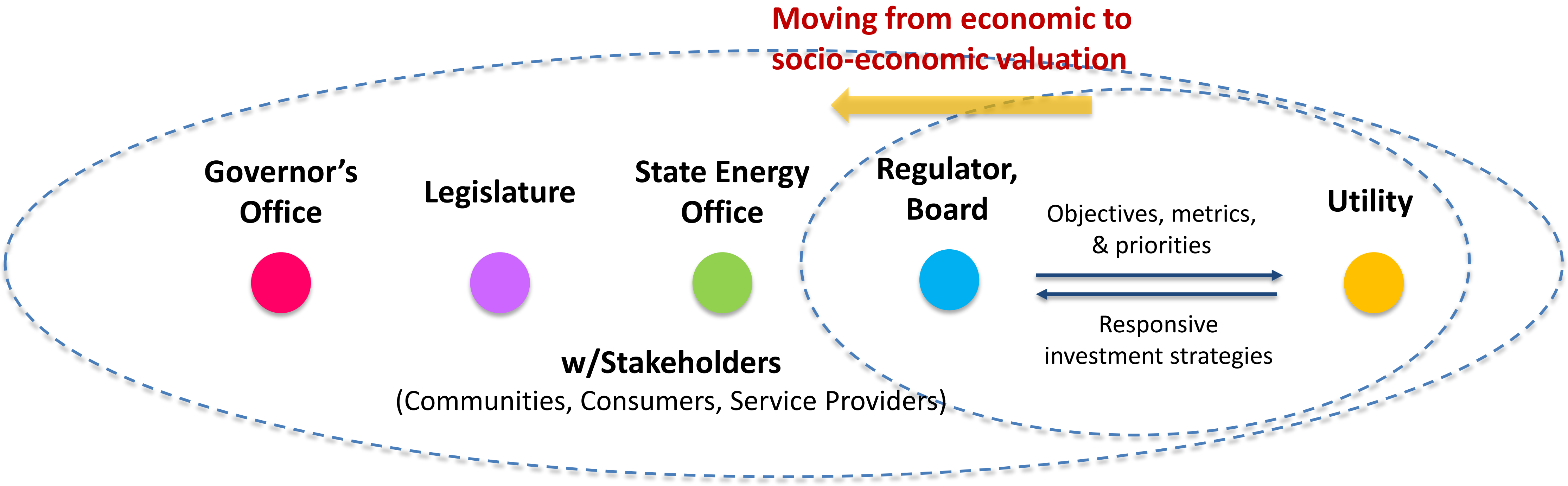
Monitoring and control of system state to enable adaptive response capabilities in real-time and for predictive analysis (modeling, simulation, and analytical platforms)

Real-time control and coordination of system assets, including inverter-based resources (DERs), and microgrids to adapt to emergency situations

Note: FPL and more advanced utilities undertake continuous improvement of hardening and asset management practices and have built information platforms for emergency crews. Utilities e.g., PJM and Austin Energy are also implementing real-time sensing and controls to mitigate wildfires and control assets under emergency conditions. All the above activities are in play and best practices are available.

Formulation of Objectives and Priorities

The shift towards evaluating grid investments based on socio-economic issues, e.g., resilience and equity concerns, will require collaborative efforts among community and state officials with their stakeholders to formulate objectives, metrics, and priorities to guide the efforts of utilities



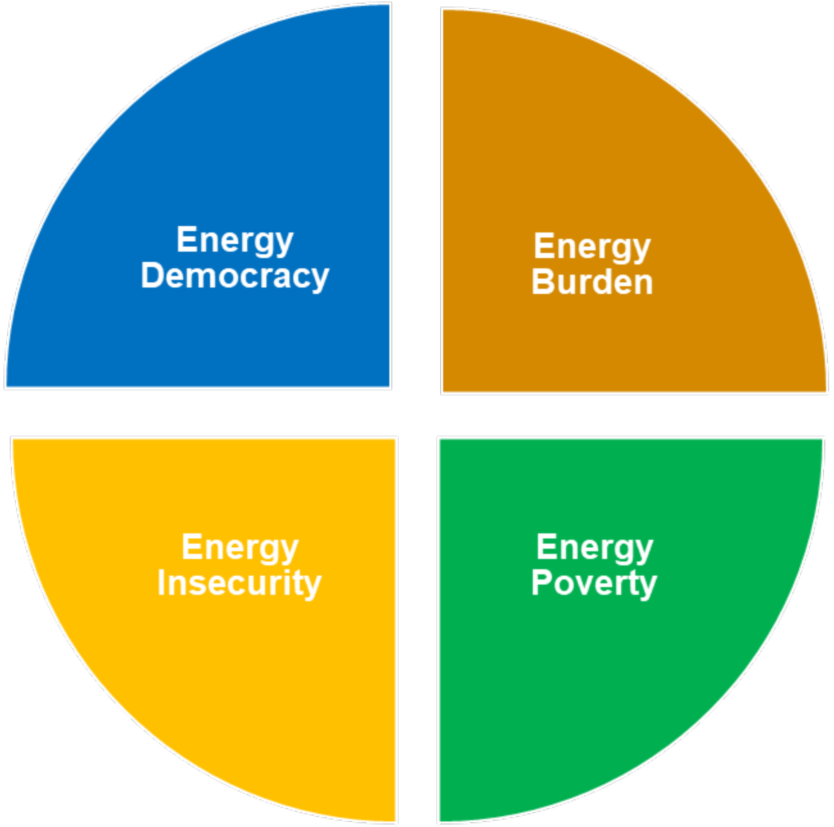
Resilience Planning Components (from HECO Resilience Working Group)

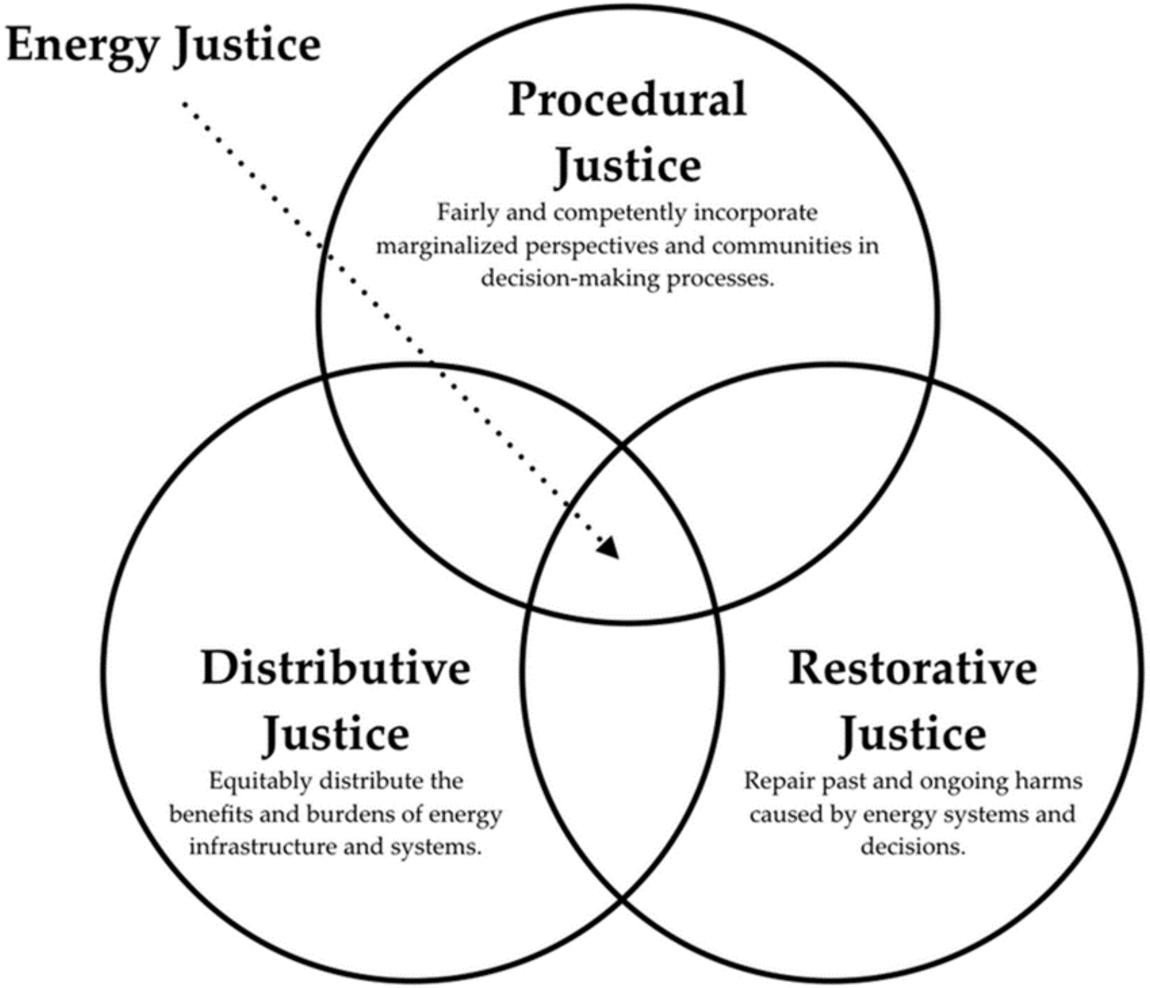
Conducted jointly with stakeholders. Utilities perform engineering analysis to determine impacts, assess gaps, and develop solution options.

Source: *Resilience Working Group Report for Integrated Planning*, Hawaiian Electric Company, Maui Electric Company, and Hawai`i Electric Light Company, prepared by Siemens Industry, Inc., April 2020; [Resilience Working Group Report (hawaiianelectric.com)]

Determine planning objectives and metrics	Sample Objectives (from Hawaii RWG): • Reduce outage risk during severe events • Increase ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially catastrophic event • Reduce restoration and recovery time following a severe event • Optimize cost (including capital and operating costs) • Return critical and priority customers' power within specified time • Return power to other customers within specified time Resilience Metric (from Hawaii RWG): Resilience Index that tracks restoration times with stated targets for critical, priority, and other customers
Identify and prioritize threats	Perform a threat assessment with key federal, state, and local stakeholders, as appropriate, to identify the potential threats and assess the risk of their probable impacts. See: FEMA Comprehensive Preparedness Guide (CPG) 201, Table 1, for a comprehensive list of threats (https://www.fema.gov/sites/default/files/2020-04/CPG201Final20180525.pdf)
Develop threat scenario reference cases	Develop reference cases for each threat scenario (e.g., low, moderate, severe) that characterize the threat and its impact on the grid, customers, and other critical infrastructures (e.g., hospitals, water/wastewater treatment, vulnerable individuals/populations, telecommunications, energy, and emergency services). Apply forecasts of future weather/climate threats.
Tiering and prioritization of key customers and infrastructure	Identify and prioritize key customers and infrastructure sectors with focus on system recovery and public safety and well-being: • Develop and apply criteria for identifying/prioritizing key customers and infrastructure based on priority and urgency. Categorize by tiers, e.g., Tier 1 represents critical customers/infrastructures, Tier 2 represents priority customers/infrastructures, and Tier 3 represents all others. (Hawaii criteria are on page 40.) Criteria development is a shared responsibility of the critical infrastructure sectors. • Alignment of tiering and prioritization needed with sectors/customers under existing emergency management, homeland security, and hazard mitigation/resiliency frameworks.
Determine capability gaps and solutions	Determine gaps in capabilities, including utility capabilities and self/back-up supply capabilities and requirements, and develop solutions. Apply cost-effectiveness framework (BCA vs least-cost/best-fit). Key customers and critical infrastructure owners/operators partner with utilities, other energy companies, and the government in developing local resilience solutions that can provide resilient power for essential service providers and enhance the overall resilience of the grid for all customers in mutually beneficial projects. Considerations include: • Implementing asset hardening practices, where needed • Developing and implementing load management/load curtailment capabilities • Maintaining ample onsite fuel supplies • Deployment of temporary emergency power generators • Partnering with utilities and the government to develop local microgrids • Utilizing grid-forming inverters so that renewables and DERS can provide a black-start capability • Ensuring availability of adequate road clearing equipment to speed recovery of key roads, etc.

Dimensions & Approaches of Energy Equity





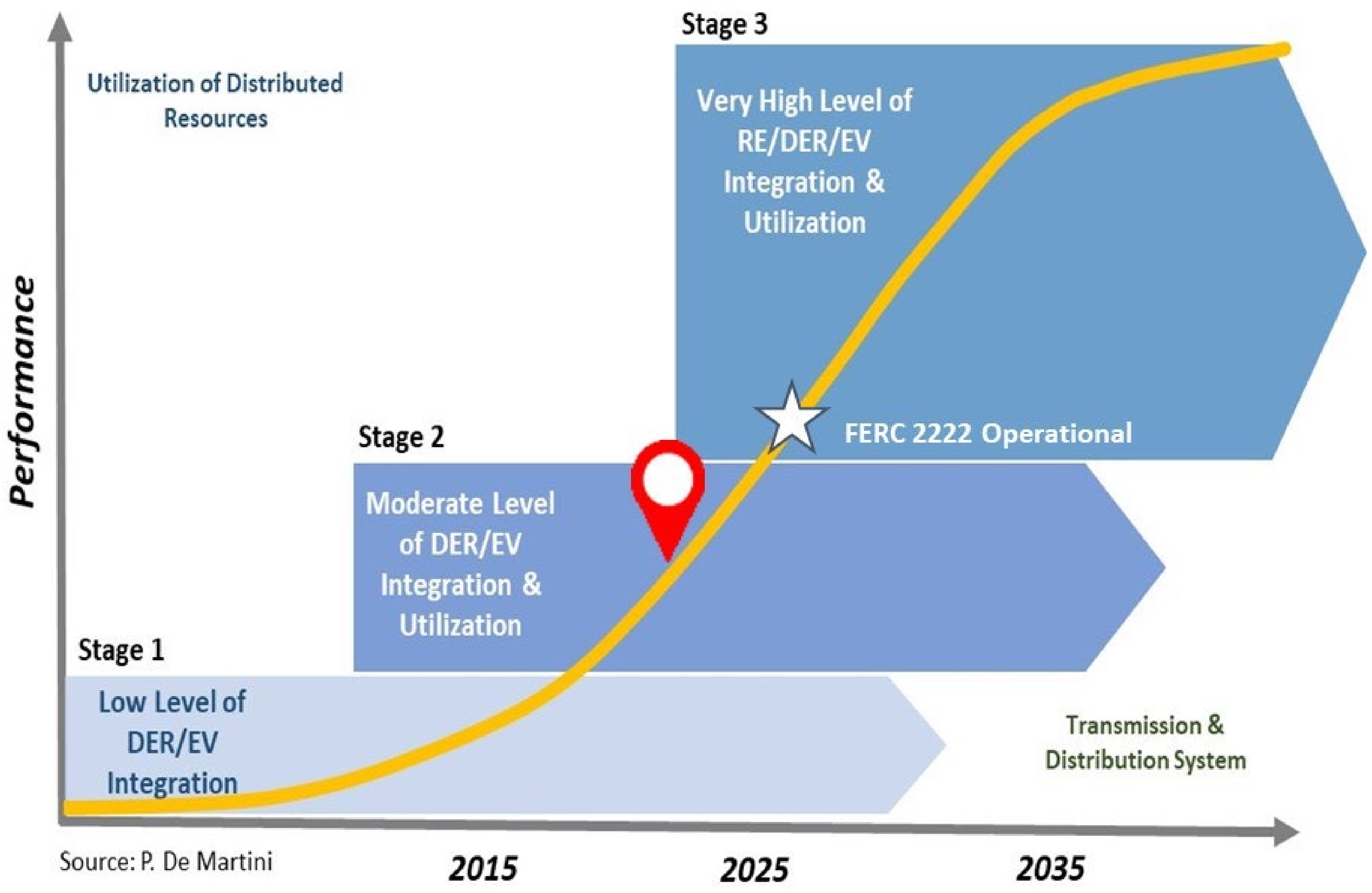
Source: Energy Justice Workbook; [Section 1 - Defining Energy Justice: Connections to Environmental Justice, Climate Justice, and the Just Transition - Initiative for Energy Justice (iejusa.org)]

Energy Equity Metrics

Procedural and Recognition (due process and accountability)	**Distributive** (affordability and availability)	**Restorative** (intra- and inter-generational sustainability and responsibility
• Representativeness and inclusiveness of planning processes for all affected stakeholders • Responsiveness of planning processes to public participation and fairness of decisions • Transparency of planning processes and decisions	• Electricity cost burden (i.e., household electricity bills/income) • Electricity affordability gap • Electricity quality (e.g., geographic disaggregation of outage frequency/severity; restoration efficiency) • Electricity program (e.g., tax credits; energy efficiency) and technology (e.g., BTM solar and storage) accessibility and performance (e.g., participation/investment demographics; distribution of savings/costs, reliability/resilience, or other benefits/burdens) • Social burden (i.e., effort and ability to access critical services)	• Economic (e.g., job training/job quality; energy resource ownership/governance; reparation of electricity cost burden shouldered by energy burdened communities) • Environmental (e.g., natural resource replenishment; generation/storage resource siting) • Social (e.g., improvements in household-human development index; establishment of safeguard/grievance redress mechanisms)

Distribution System Evolution

Increased use of distributed energy resources means additional complexity in grid planning and operations



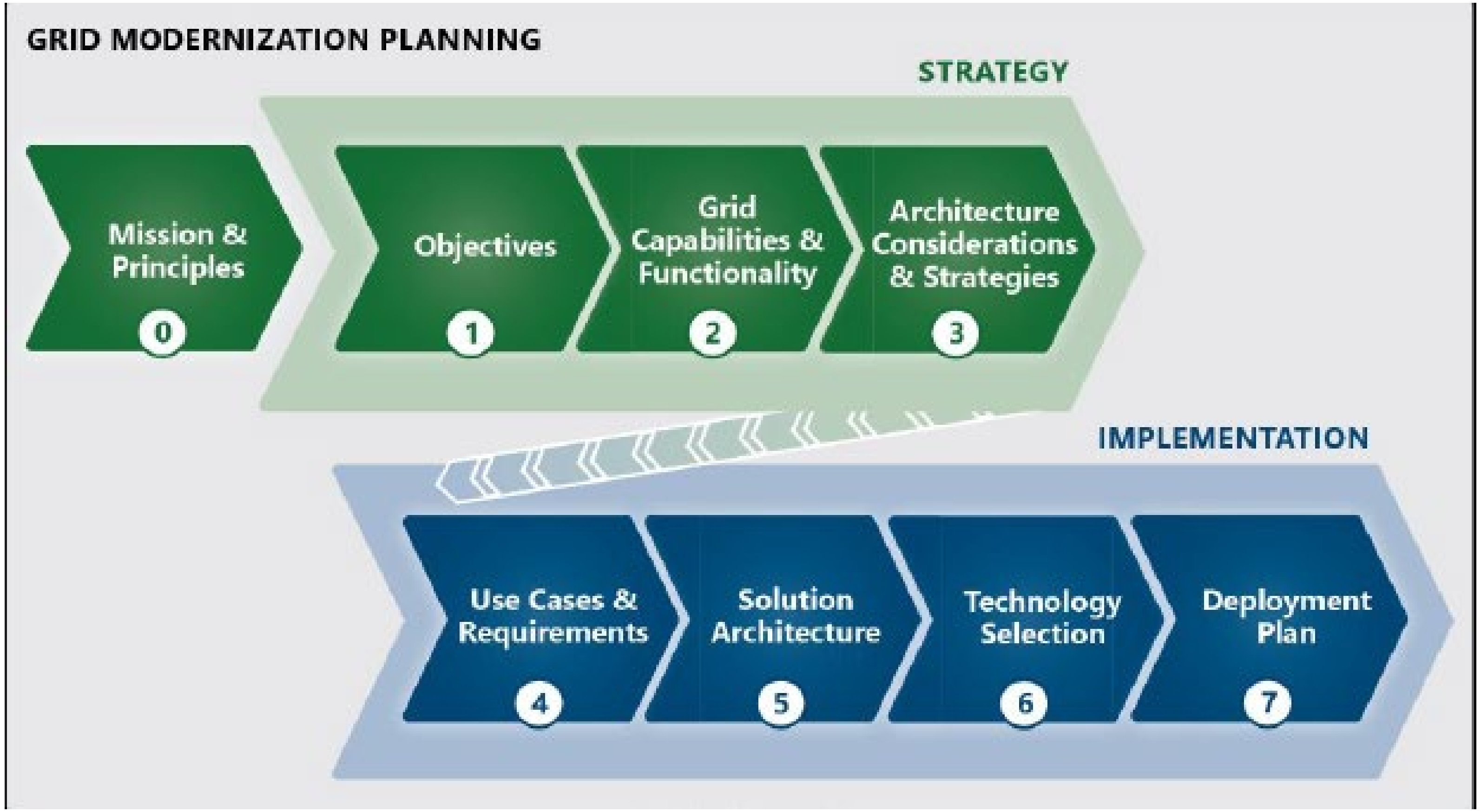
Stage 3: High DER/EV adoption; optimization and orchestration of DERs for the provision of grid services; alternative grid and ownership structures, including community microgrids; interjurisdictional coordination of markets, planning, and operations

Stage 2: Moderate DER adoption; emphasis on use of DERs as load-modifying and energy resources; IDP and grid modernization required to enable real-time visibility and operational use of DERs

Stage 1: Low DER adoption; emphasis on reliability, resilience, and operational efficiency; no material change to infrastructure, planning, and operations

Grid Modernization Strategy & Implementation Planning

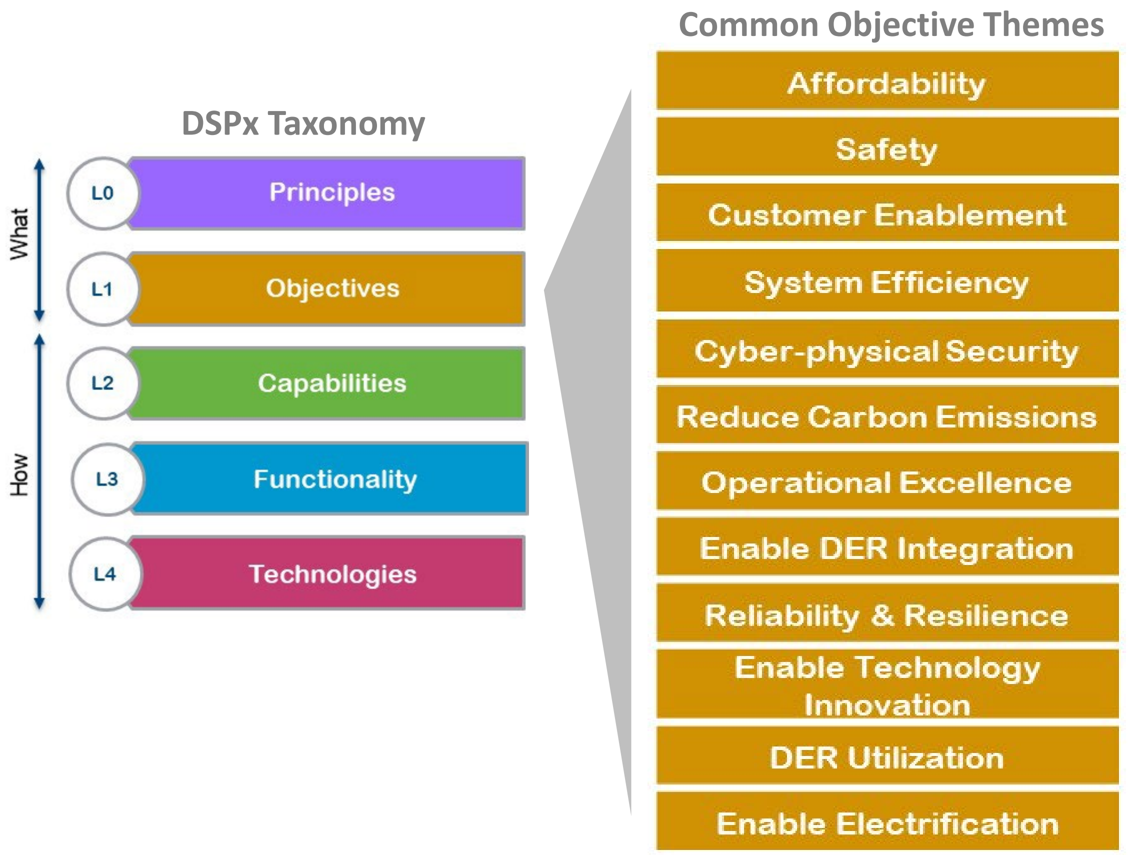
Community/state policy objectives, metrics, and priorities, combined with customer demand and DER/EV forecasts, are key inputs into the formulation of grid modernization strategies. These strategies should holistically address both functional and structural capabilities needed over time. Such strategies can then inform decisions on the selection and staged deployment of technology.



Source: *Modern Distribution Grid Guidebook, Strategy & Implementation Planning Guidebook*, Version 1.0 Final Draft, DOE Office of Electricity, June 2020; [Modern-Distribution-Grid_Volume_IV_v1_0_draft.pdf (pnnl.gov)]

Objectives Drive Grid Modernization Planning

Without clear objectives, it becomes difficult to assess whether resulting plans are responsive and if key stakeholders will accept them



PUC of Ohio Planning Objectives:*

- **A Strong Grid:** A distribution grid that is reliable and resilient, optimized and efficient and planned in a manner that recognizes the necessity of a changing architectural paradigm.
- **The Grid as a Platform:** A modern grid that serves as a secure open access platform—firm in concept and as uniform across our utilities as possible—that allows for varied and constantly evolving applications to seamlessly interface with the platform.
- **A Robust Marketplace:** A marketplace that allows for innovative products and services to arise organically and be delivered seamlessly to customers by the entities of their choosing.
- **The Customer's Way:** An enhanced experience of the customer's choosing on the application side, whether for reasons arising from financial, convenience, control, environmental, or any other chosen consideration.

Note: The 'safe, reliable, and affordable' components were included in the mission statement, which was incorporated into the principles of the PowerForward Roadmap.

*Source: *PowerForward: A Roadmap to Ohio's Electricity Future*, Public Utilities Commission of Ohio, June 2020; PUCO+Roadmap.pdf (ohio.gov).

Distribution System Capabilities

Inputs into the planning process enable the determination of functional requirements needed over time

Distribution System Planning	Distribution Grid Operations		Distribution Market Operations
Scalability 3.1.1	Operational Risk Management 3.2.1	Situational Awareness 3.2.2	Distribution Investment Optimization 3.3.1
Impact Resistance and Impact Resiliency 3.1.2	Controllability and Dynamic Stability 3.2.3	Management of DER and Load Stochasticity 3.2.4	Distribution Asset Optimization 3.3.2
Open and Interoperable 3.1.3	Contingency Management 3.2.5	Security 3.2.6	Market Animation 3.3.3
Accommodate Tech Innovation 3.1.4	Public and Workforce Safety 3.2.7	Fail Safe Modes 3.2.8	System Performance 3.3.4
Convergence w/ Other Critical Infrastructures 3.1.5	Attack Resistance/Fault Tolerance/Self-Healing 3.2.9	Reliability and Resiliency Management 3.2.10	Environmental Management 3.3.5
Accommodate New Business Models 3.1.6	Integrated Grid Coordination 3.2.11	Control Federation and Control Disaggregation 3.2.12	Local Optimization 3.3.6
Transparency 3.1.7	Privacy and Confidentiality 3.2.13		

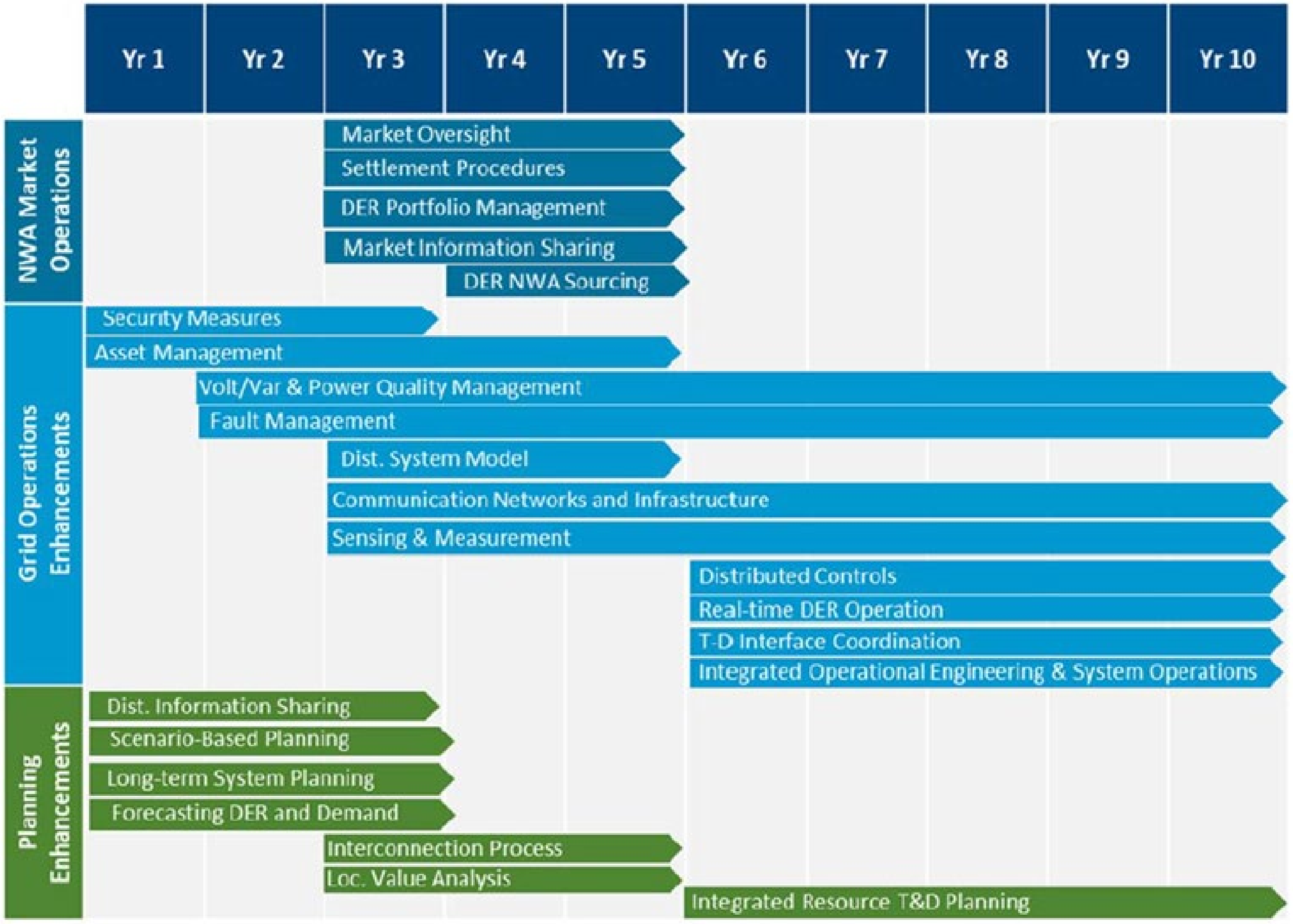
Source: *Modern Distribution Grid, Volume I: Customer and State Policy Driven Functionality,* DOE-OE, 2017; Modern-Distribution-Grid_Volume-I_v1_1.pdf (pnnl.gov)

Mapping Technologies to Objectives (Example)

Objective	Attribute	Capability	Function	Technology
Enable customer choice	Information to support customer decisions	Provide online customer access to relevant & timely information by 2020 for small business & residential customers	Remote meter data collection & verification Customer data management Energy management & DER purchase analysis	Customer Portal Customer analytic tools Greenbutton Time interval metering Meter Data Management System Customer Info System Data Warehouse Meter communications

Source: *Modern Distribution Grid, Volume I: Customer and State Policy Driven Functionality, DOE, 2017;* Available online at: https://gridarchitecture.pnnl.gov/media/Modern-Distribution-Grid_Volume-I_v1_1.pdf

NH PUC's Staff Conceptual Functional Roadmap



Source: *Staff Recommendation on Grid Modernization*, New Hampshire Public Utilities Commission, January 31, 2019;
[Microsoft Word - Grid Mod Report FINAL! (nh.gov)]

Grid Architecture Focuses on Structure*

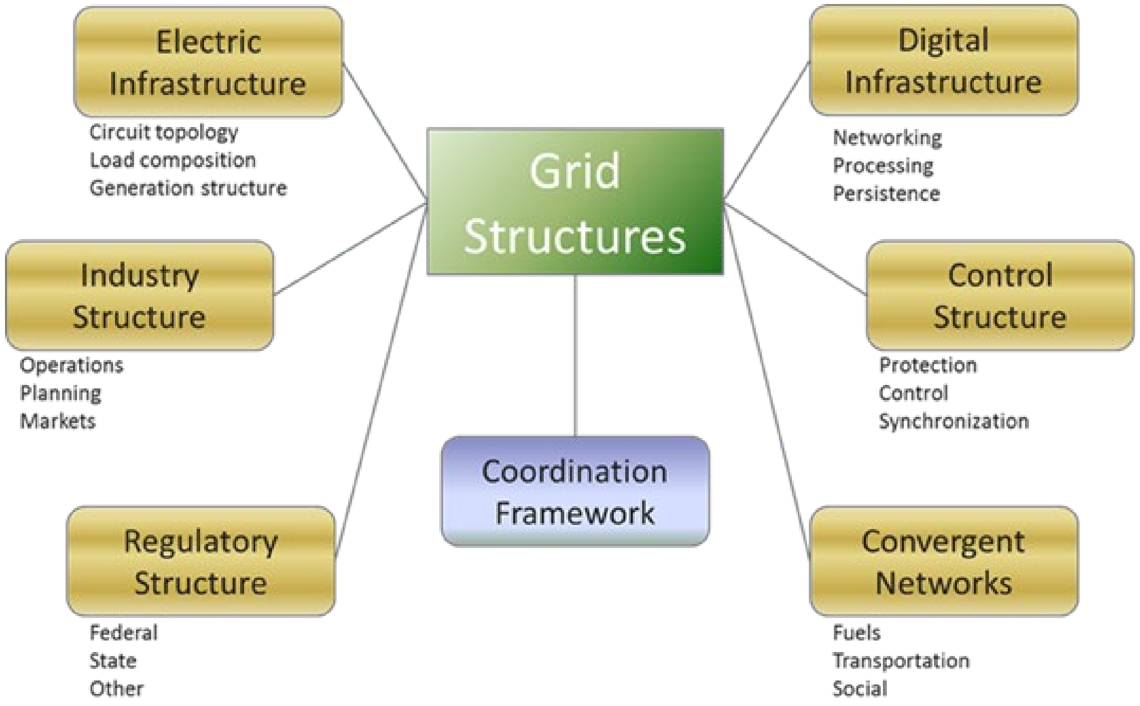
Structure sets the essential bounds on system capabilities

We have inherited much legacy grid structure

Key grid architecture problem: Determining minimal changes needed to

- relieve structural constraints
- enable new capabilities
- strengthen grid characteristics

*From Jeffrey Taft, PNNL Grid Architect, retired



- Get the structure right and all the pieces fit into place neatly, all the downstream decisions are simplified, and investments are future-proofed
- Get the structure wrong and integration is costly and inefficient, investments are stranded, and benefits realization is limited

Architecture Manages Complexity*

The engineering issues associated with the scale and scope of dynamic resources envisioned in policy objectives for grid modernization requires a holistic architectural approach

So, pick-up a pencil

Before trying to hang windows

*From Jeffrey Taft, PNNL Grid Architect, retired

Resist temptation to start with technology choices

Architectural Considerations*

Grid architecture is primarily about structure and ensuring coherence

- ***Coordination*** **is the process that causes or enables a set of decentralized elements to cooperate to solve a common problem**
  - How will we coordinate utility and non-utility assets?
  - How will we address the information sharing requirements among participants?
- ***Scalability*** **is the ability of a system to accommodate an expanding number of endpoints or participants without having to undertake major rework**
  - How do we enable optimal performance locally and system-wide?
  - How do we minimize the number of communication interfaces (cyber-intrusion)?
- ***Layering*** **is applying fundamental or commonly-needed capabilities and services to a variable set of uses or applications through well-defined interoperable interfaces (Leads to the concept of *platform*)**
  - How do we build out the fundamental components of the system to support new applications and convergence with other infrastructures?
- ***Buffering*** **is the ability to make the system resilient to a variety of perturbations**
  - How do we address resilience and system flexibility requirements (role of storage)?

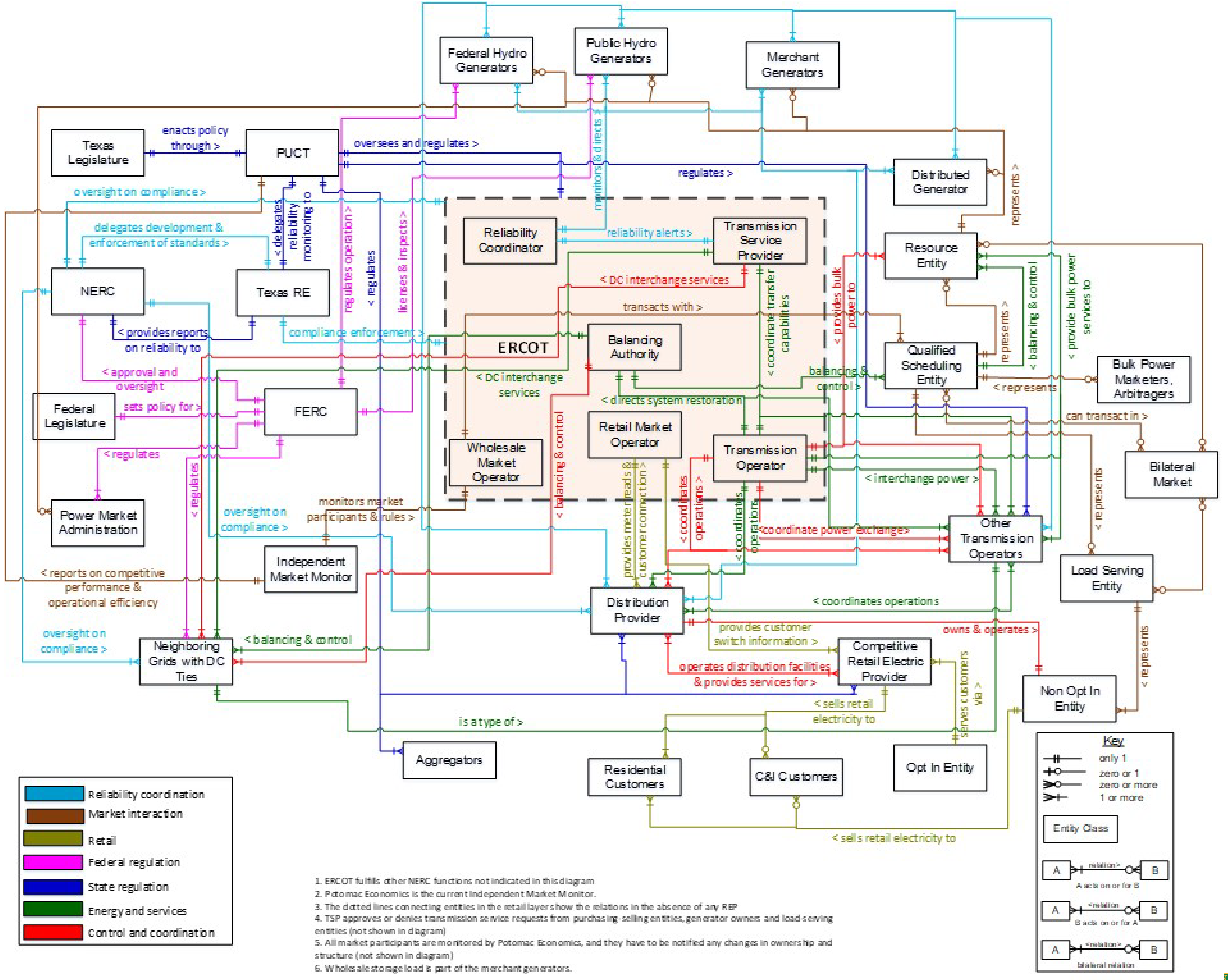
*From Jeffrey Taft, PNNL Grid Architect, retired

ERCOT Industry Structure Model*

Understanding industry relationships helps to determine coordination requirements. What are the:

- Respective roles and responsibilities of the participants,
- Data/information sharing requirements, including latency considerations, and
- Sensing, communication, control, and computing requirements to support the above?

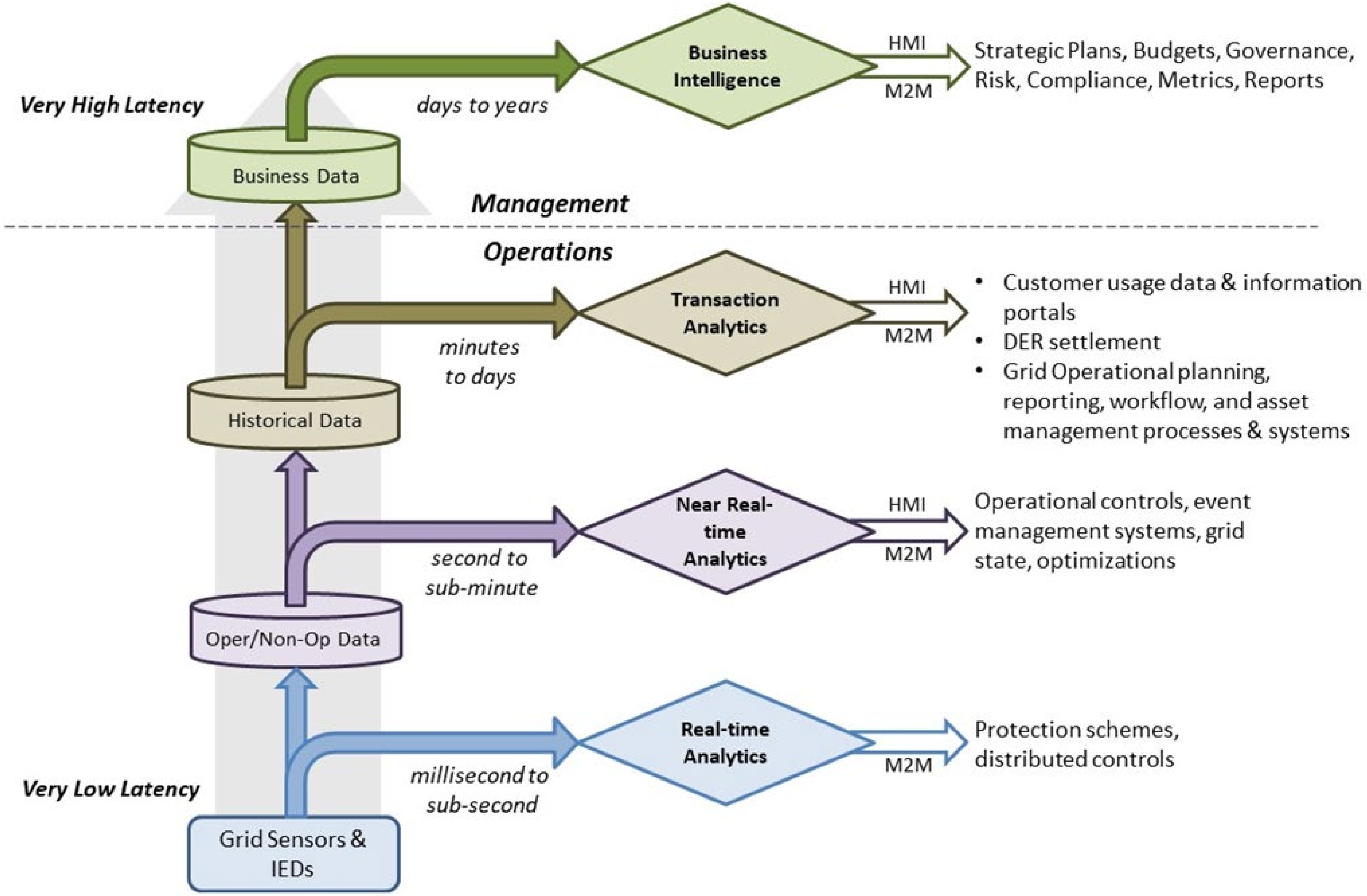
*From Jeffrey Taft, PNNL Grid Architect, retired



1. ERCOT fulfills other NERC functions not indicated in this diagram
2. Potomac Economics is the current Independent Market Monitor.
3. The dotted lines connecting entities in the retail layer show the relations in the absence of any REP
4. TSP approves or denies transmission service requests from purchasing selling entities, generator owners and load serving entities (not shown in diagram)
5. All market participants are monitored by Potomac Economics, and they have to be notified any changes in ownership and structure (not shown in diagram)
6. Wholesale storage load is part of the merchant generators.

Observability Drives Data Requirements*

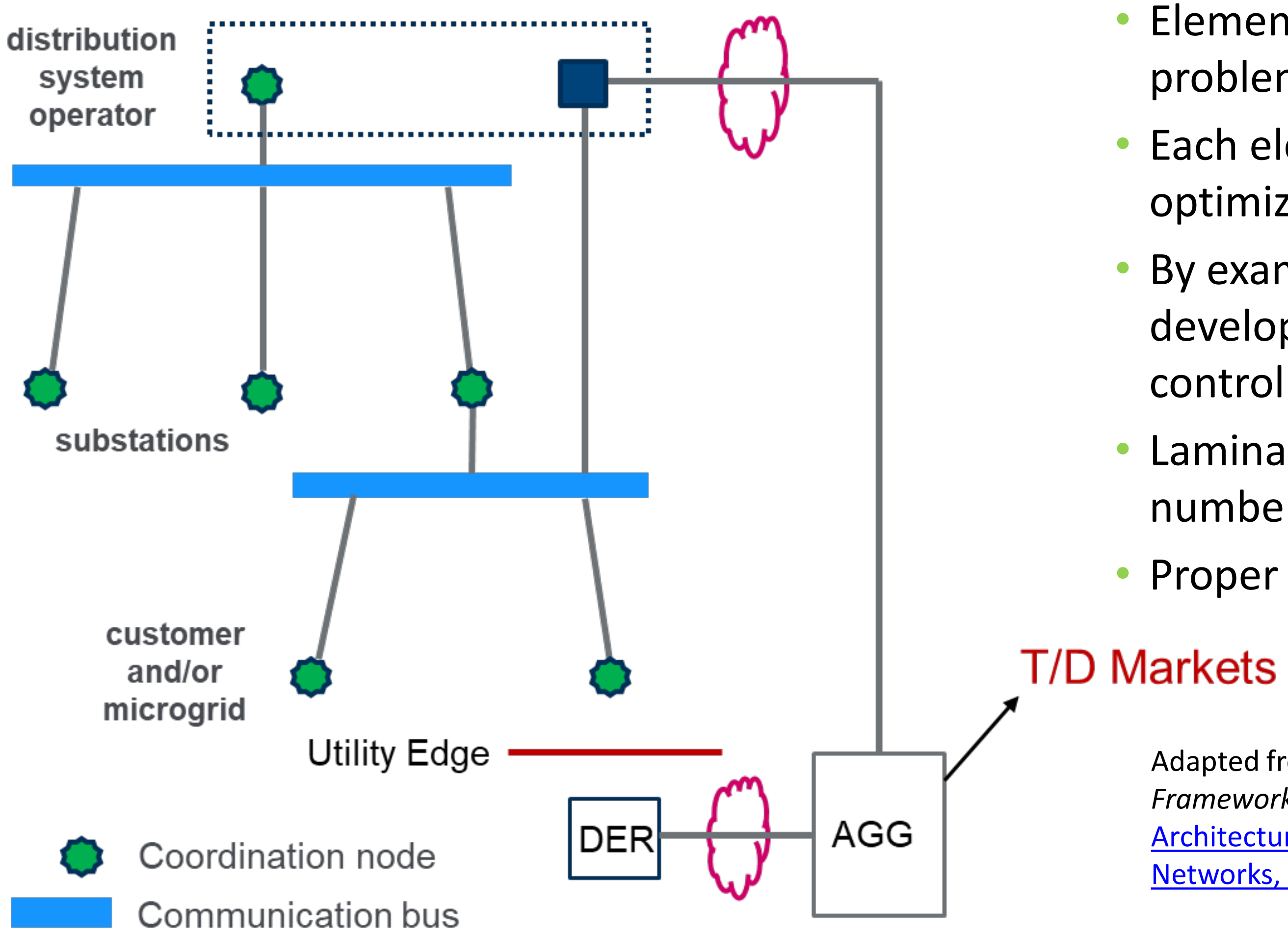
Time sensitivity of specific data/information defines communications requirements and the need for an architectural layering to support the unique needs for multiple applications



*From work performed jointly by Paul De Martini, Newport Consulting Group, and Jeffrey Taft, PNNL Grid Architect, retired

Coordination of DER and Optimization

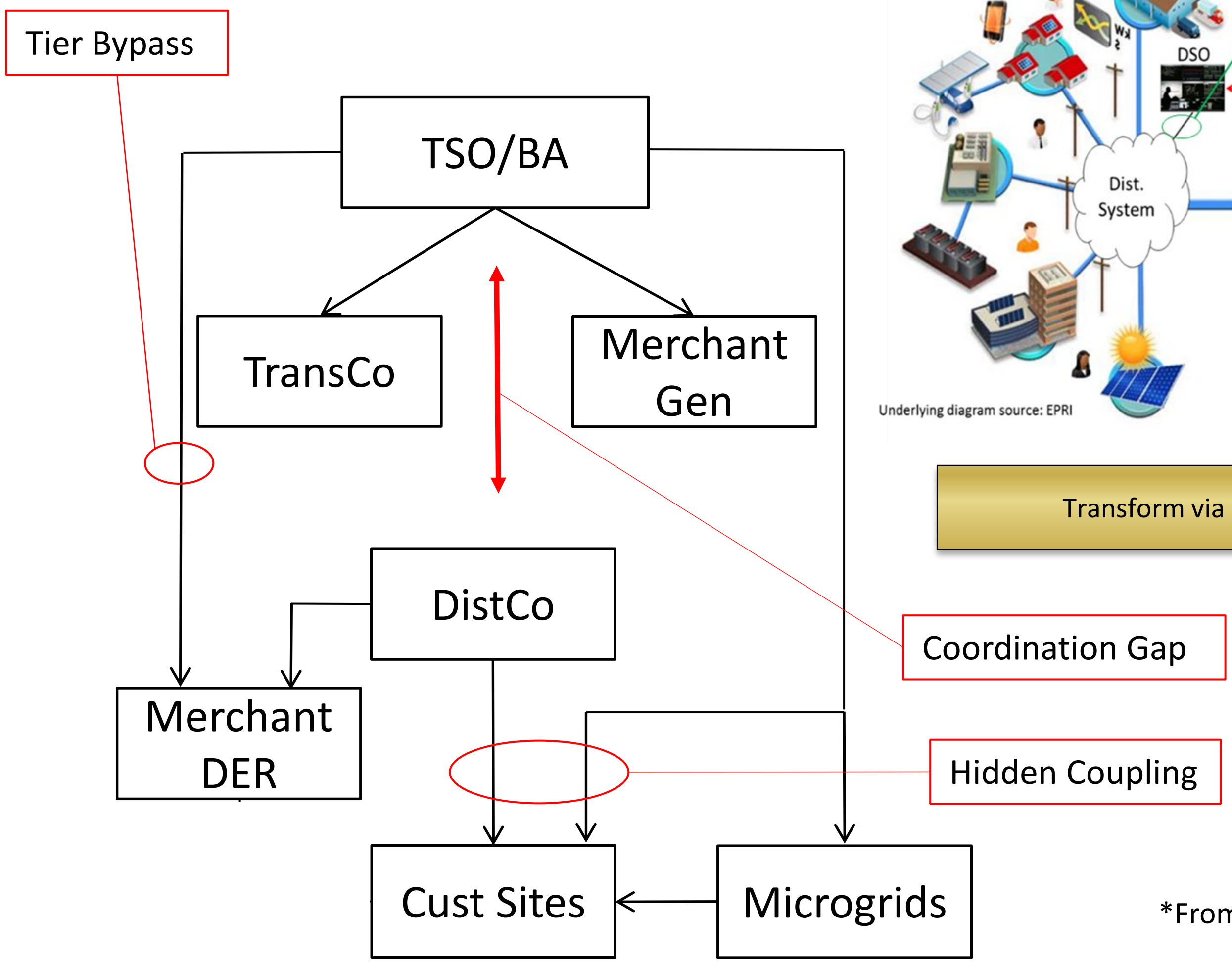
The presence of DER not owned by utilities changes the problem from direct control to a combination of control and coordination

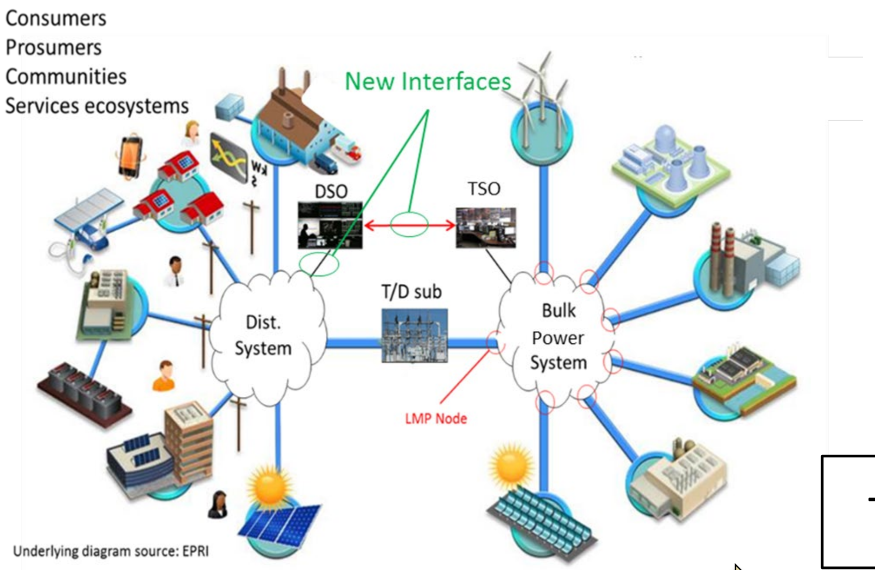


- Elements need to coordinate to solve common problems of grid operations (in the presence of DER)
- Each element has performance constraints and optimization objectives
- By examining relationships and interfaces, we can develop coordination frameworks and underlying control and communication requirements
- Laminar coordination allows us to manage an increasing number of nodes
- Proper coordination permits local/system optimization

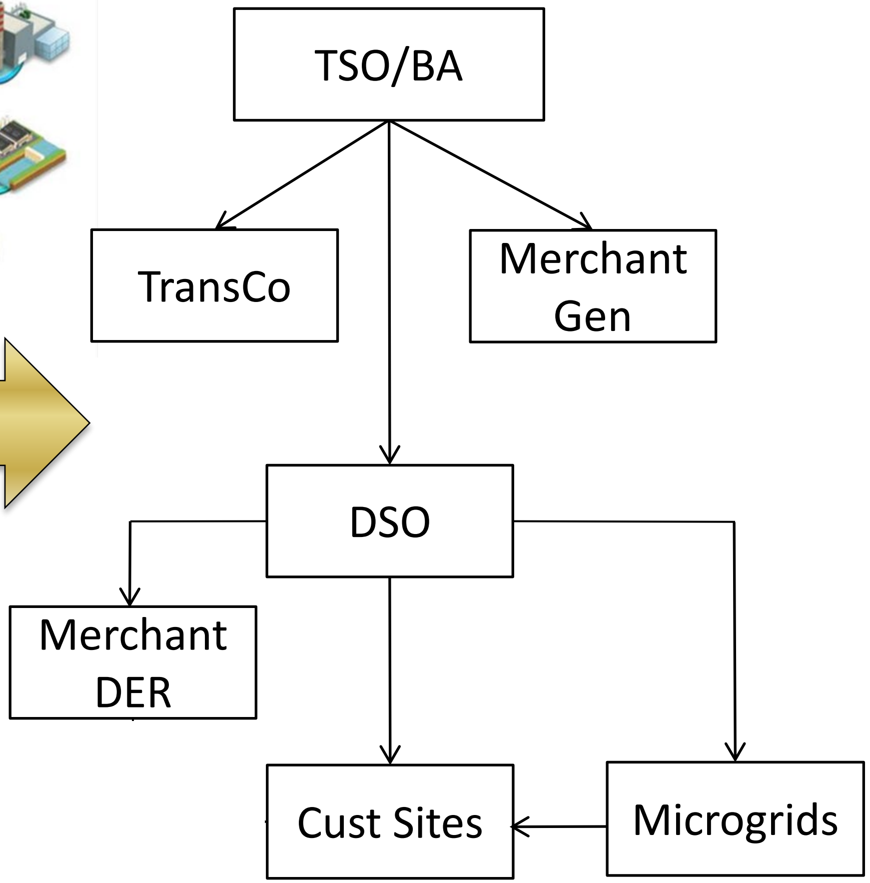
Adapted from *Architectural Basis for Highly Distributed Transactive Power Grids: Frameworks, Networks, and Grid Codes*, JD Taft, PNNL-25480, June 2016; [Architectural Basis for Highly Distributed Transactive Power Grids: Frameworks, Networks, and Grid Codes (pnnl.gov)]

T/D/BTM Coordination via Layered Decomposition*





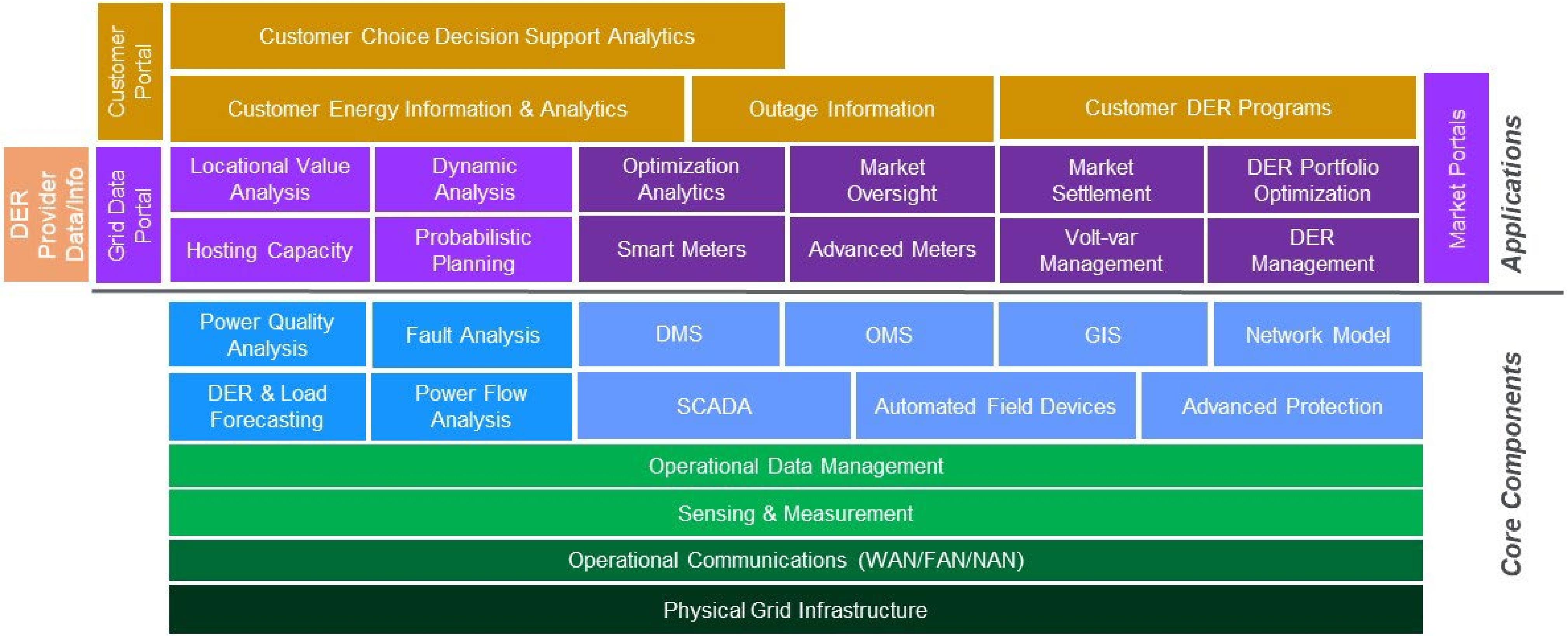
Transform via Layered Decomposition



*From Jeffrey Taft, PNNL Grid Architect, retired

Distribution System Platform

Applications are supported by core components

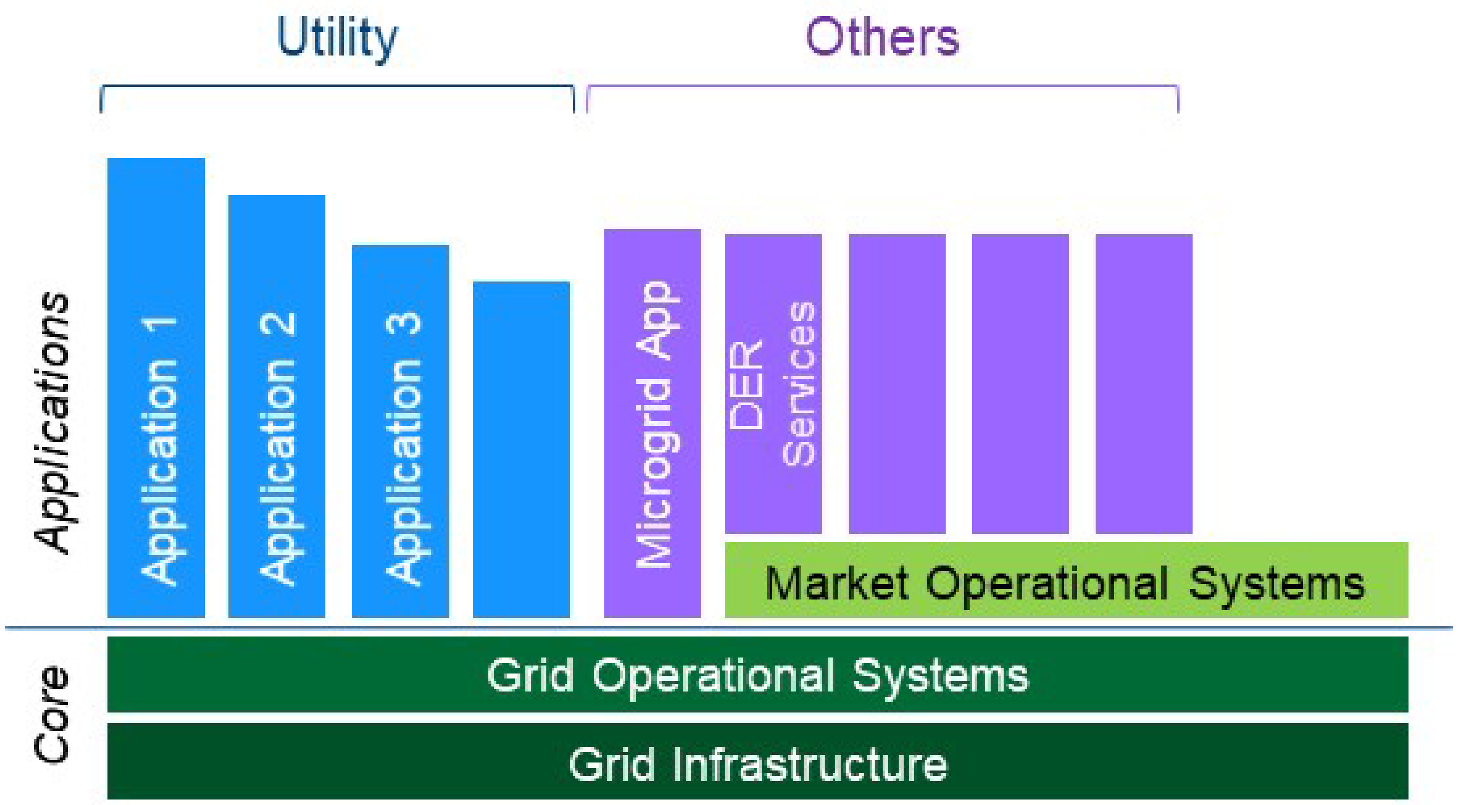


Green - Core Cyber-physical layer
Blue - Core Planning & Operational systems
Purple - Applications for Planning, Grid & Market Operations
Gold - Applications for Customer Engagement with Grid Technologies
Orange - DER Provider Application

From Modern Distribution Grid Guidebook, DSPx Volume 4, June 2020; PNNL: Grid Architecture - Modern Distribution Grid Project

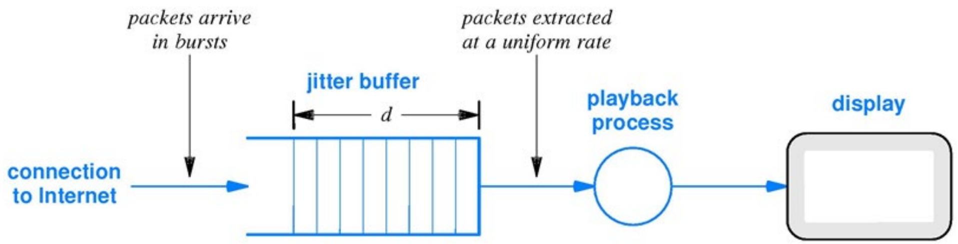
Convergence of Utility and Non-Utility Systems

The Grid as a Platform: *A modern grid that serves as a secure open access platform—firm in concept and as uniform across our utilities as possible—that allows for varied and constantly evolving applications to seamlessly interface with the platform.* **Public Utility Commission of Ohio**



Source: P. De Martini

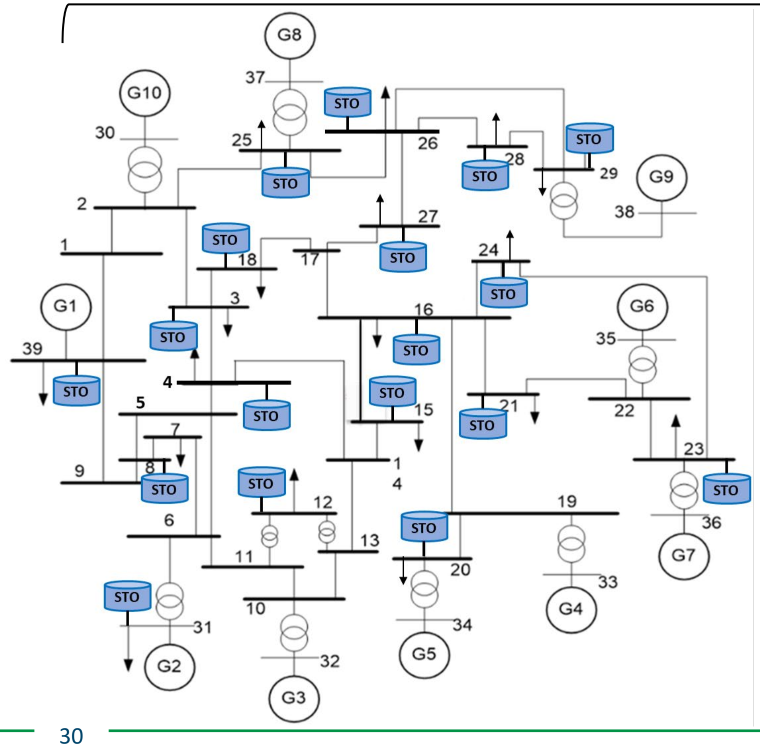
Grid Buffering via Coordinated Storage Networks (conceptual example)*

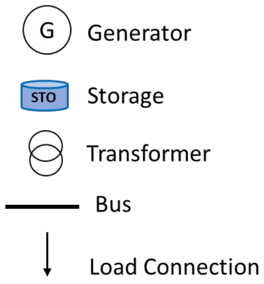


Buffering is common in all complex system except power grids.

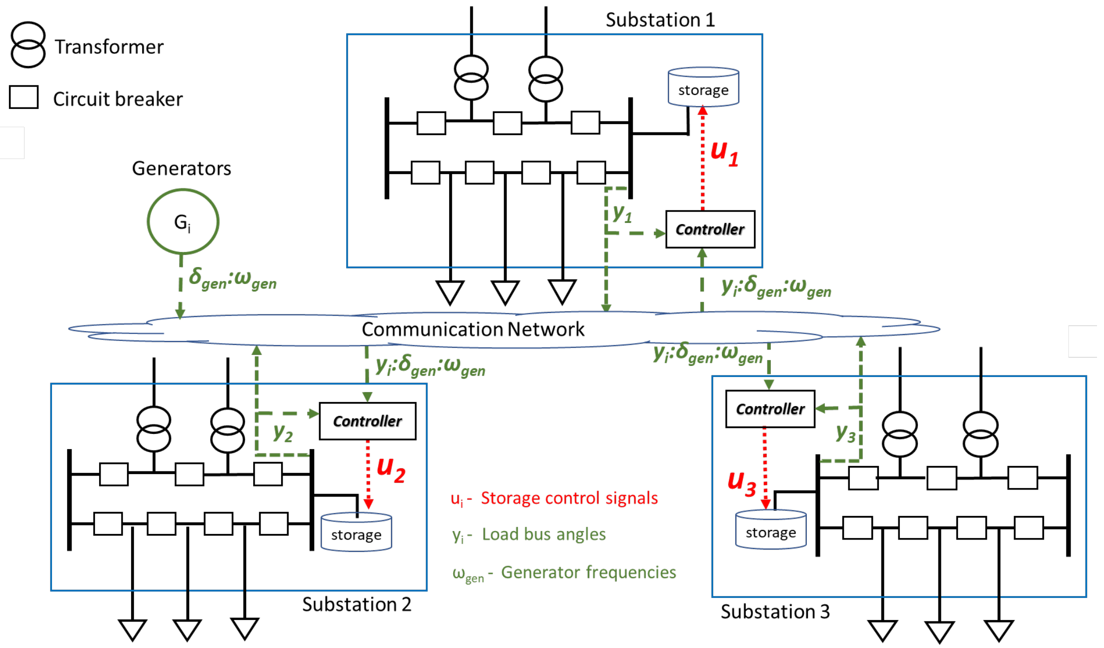
Concept: systemic use of storage as a grid "shock absorber" to improve grid flexibility and resilience, instead of point use for grid services and reliability.

Apply storage as a general system component; coordinate their actions.



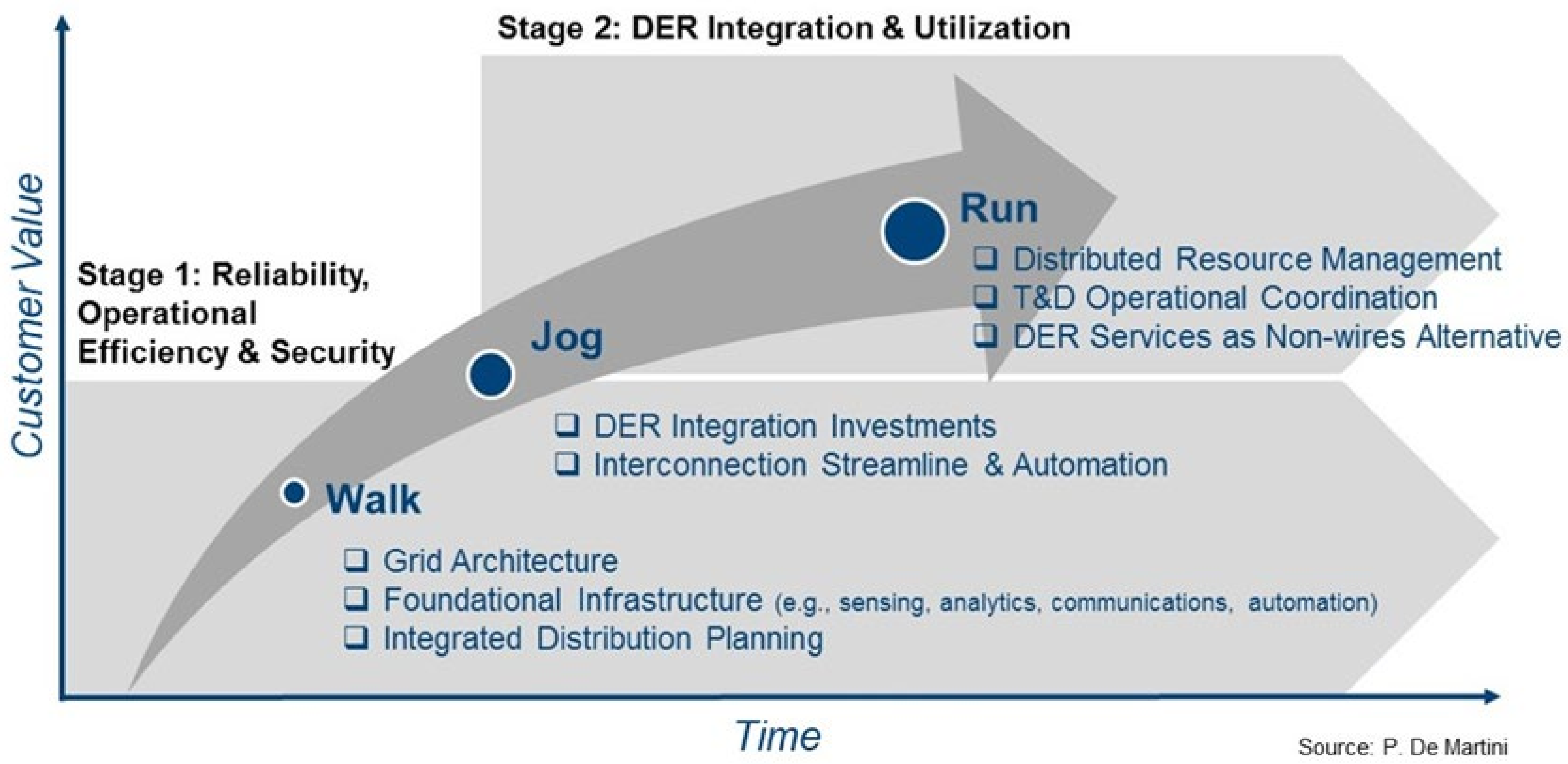


*From Jeffrey Taft, PNNL Grid Architect, retired



Proportional Investment (Walk-Jog-Run Deployment)

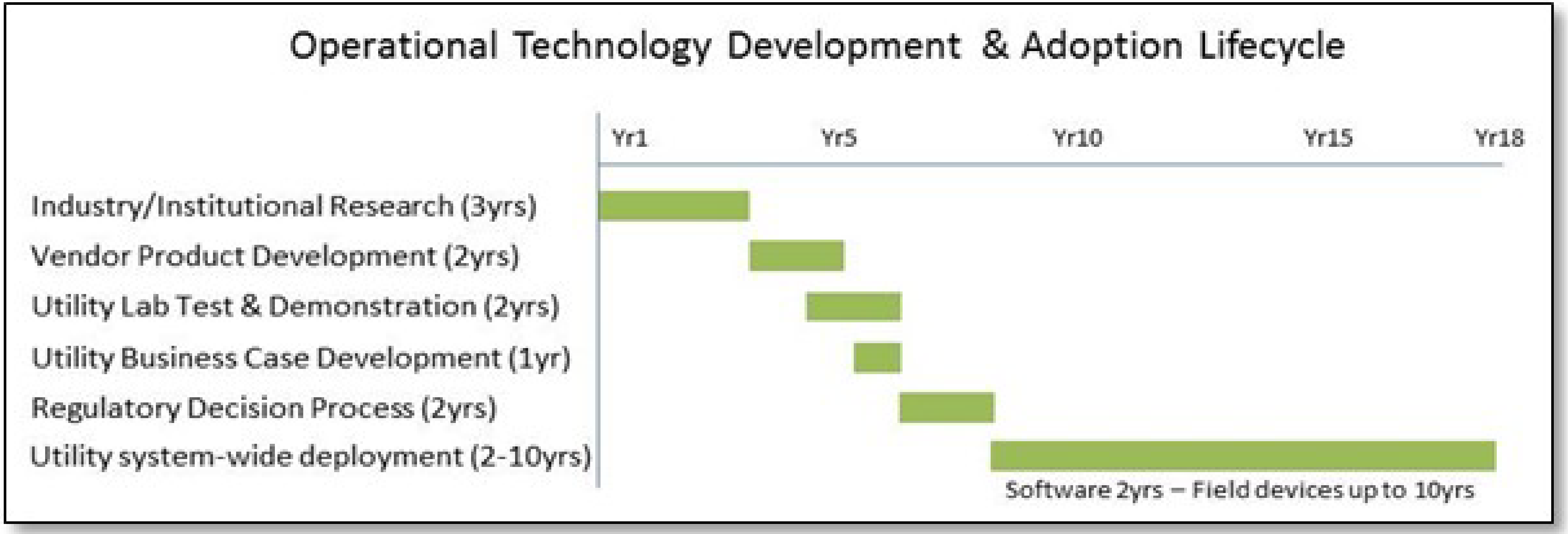
Grid modernization investments can be deployed proportionally, both temporally and spatially, according to need



Source: P. De Martini

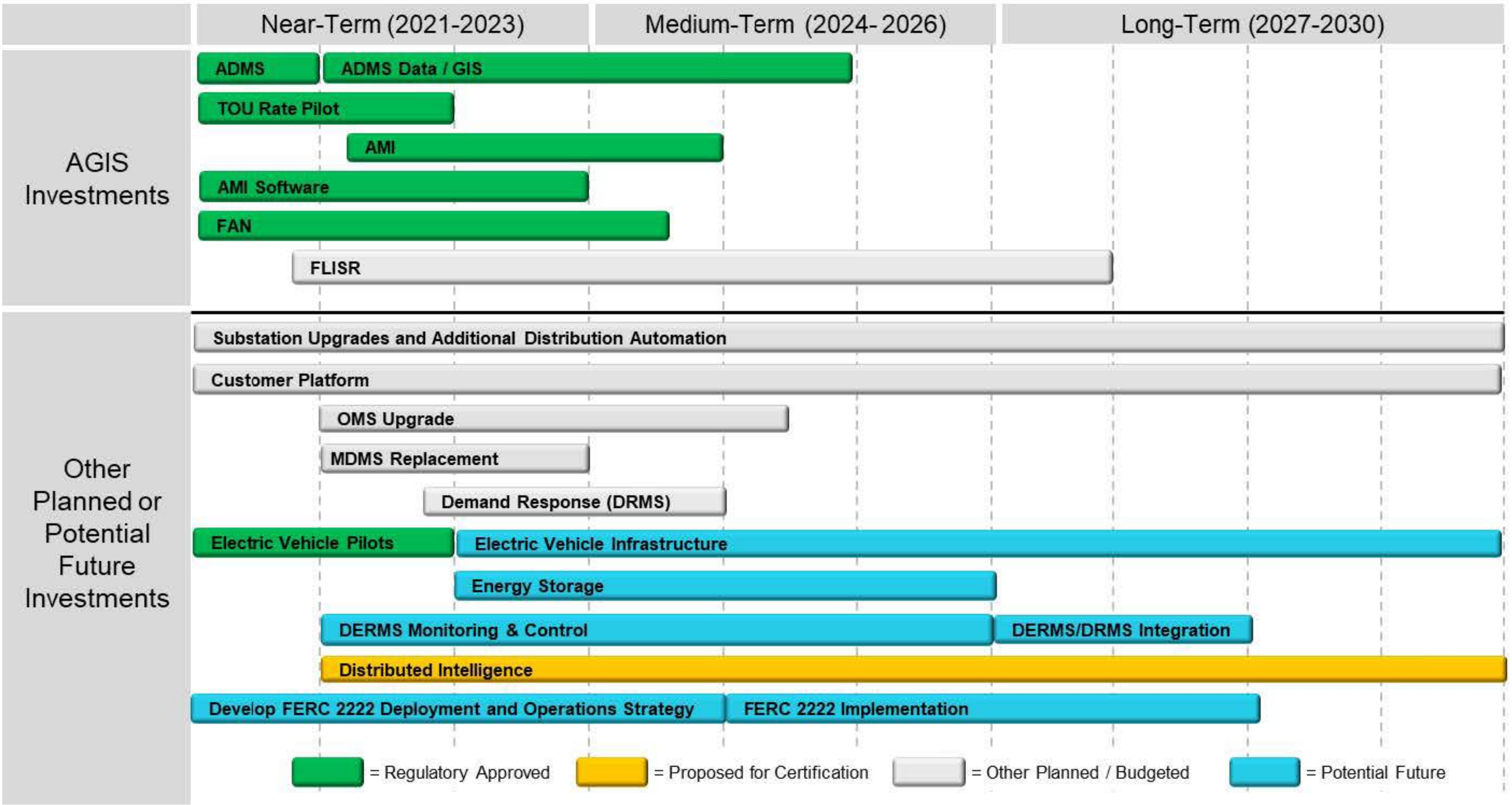
Technology Adoption Timing Considerations

Required efforts to develop, demonstrate, test, and deploy new technologies are incorporated into an IDSP grid modernization strategy



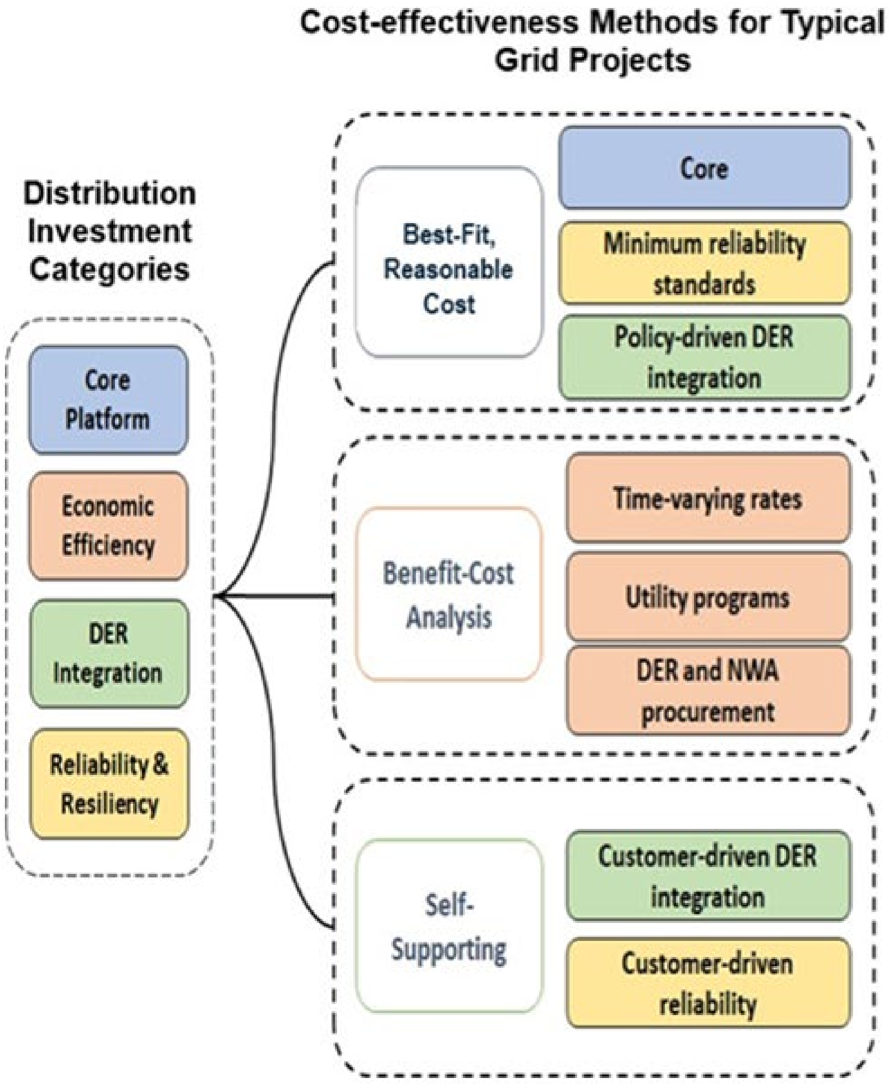
Xcel Energy 10-Year Grid Mod Roadmap

Xcel Energy's roadmap reflects a staged and proportional technology deployment strategy based on need



Source: *Integrated Distribution Plan 2022-2031*, Northern States Power Company, Xcel Energy, November 2021, [searchDocuments.do (state.mn.us)]

Grid Modernization Cost-Effectiveness Framework



Best-Fit, Most-Reasonable-Cost for core grid platform and grid expenditures required to maintain or reliable operations as well as integrate distributed resources connected behind and in front of the customer meter that may be socialized across all customers.

Benefit-Cost Analysis for grid expenditures proposed to enable public policy and/or incremental system and societal benefits to be paid by all customers. Grid expenditures are the cost to implement the rate, program or NWA. Various methods for BCA may be used.

Customer Self-supporting costs for projects that only benefit a single or self-selected number of customers and do not require regulatory benefit-cost justification. For example, DER interconnection costs not socialized to all customers. Also, undergrounding wires at customers' request.

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Thank You

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